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FUNCTIONAL SUMMARY OF THE DARPA SURAP1 NETWORK

SRNDOC9

September 1986

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In this paper, we describe the functionality of the first version of the SURAN network - SURAP1. We present the physical components, features and size of the SURAP1 network, and describe briefly how data are forwarded through the network. The paper concludes by highlighting some of the future research of the SURAN program. This paper is intended to provide a high level description of the SURAP1 network.

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FUNCTIONAL SUMMARY OF THE DARPA SURAP1 NETWORK

1. Introduction

The Survivable Radio Networks (SURAN) program was established in 1983, under the sponsorship of the Defense Advanced Research Projects Agency (DARPA), for the research and development of survivable network management and data transport protocols for large-scale packet radio networks (PRNET).

The technology for the SURAN program is based on the earlier packet radio (PR) research and development program that was initiated by DARPA in 1973 to investigate the feasibility of using packet-switched, store-and-forward radio communications to provide reliable mobile computer communications [1]. This development was motivated by the need to provide computer network access to mobile hosts and terminals, and to provide computer communications in a dynamic environment. The DARPA PRNET has evolved through the years into a robust, reliable, operational experimental network. The development process has been of an incremental, evolutionary nature; as algorithms were designed and implemented, new versions of the PRNET with increased capabilities were demonstrated. The PRNET has been in operation for experimental purposes for nearly ten years [2, 13]

In 1983, as the next step in the evolution of PR technology, DARPA began the SURAN program to develop techniques that would provide survivable communication for thousands of nodes in a dynamically changing network under severe stress conditions. Many of the features of the current PRNET are being enhanced and many new protocols are being designed to support these challenges.

As was the case with the PR program, the SURAN program is of an incremental, evolutionary nature. Successive versions of the Survivable Radio Protocol (SURAP) will be more sophisticated and provide additional functionality. In this paper, we describe the functionality of the first version of the SURAN network - SURAP1. We present the physical components, features and size of the SURAP1 network, and describe briefly how data are forwarded through the network. The paper concludes by highlighting some of the future research of the SURAN program. This paper is intended to provide a high level description of the SURAP1 network; readers who are interested in learning more about specific technical design and implementation issues are referred to the many papers cited in the SURAN bibliography [3].

2. Network Components

The PRNET is a collection of nodes that facilitate the exchange of data between terminals or computers that are geographically separated. Packets of data originate at one host or terminal and travel through this network from node to node according to addressing information contained in the packet's header and network connectivity information stored at the node, until they reach their final destination.

The PRNET system comprises

- A collection of PRs that communicate with each other via broadcast radio.
- The collection of devices (host computers, terminals, and gateways), each attached to a PR via a high-level datalink control (HDLC) wire interface, that wish to exchange data in real time.
- A network monitor that graphically displays the state of the network.

The primary component of the SURAN PRNET is the packet radio. The generation of packet radio that is supporting the SURAN research is designed to support the development and evaluation of advanced packet networking concepts and techniques. This packet radio equipment has been designated the low-cost packet radio (LPR) [4, 11] and is shown in Figure 1.

The LPR consists of both digital and RF subsystems. The RF subsystem is responsible for the transmissions and reception of packets over the radio channel. It has an omnidirectional antenna and is capable of spread-sprectrum, half-duplex transmission/reception at 400- and 100-kbps data rates. The LPR has a direct-sequence spread-spectrum waveform produced by pseudo-noise code modulation of the information bits. There are 20 RF frequencies between 1718.4 and 1840.0 MHz, 4 power levels from 14 to 37 dBm in 8-dB steps and forward error correction rates of 1/2, 3/4 and 7/8. In a SURAP1 network, FEC is fixed at 1/2, the entire network operates on the same frequency at any one time, and power is set to 37 dBm; however any of these parameters may be adjusted by operator control.

The digital subsystem executes the SURAP1 protocols that control the routing and flow of packets between PRs. The PR receives packets of data either from its attached device (i.e., host computer or terminal) via the wire interface or another PR via the radio channel. Each PR is responsible for receiving a packet and relaying it on to a PR that is one hop closer to the final

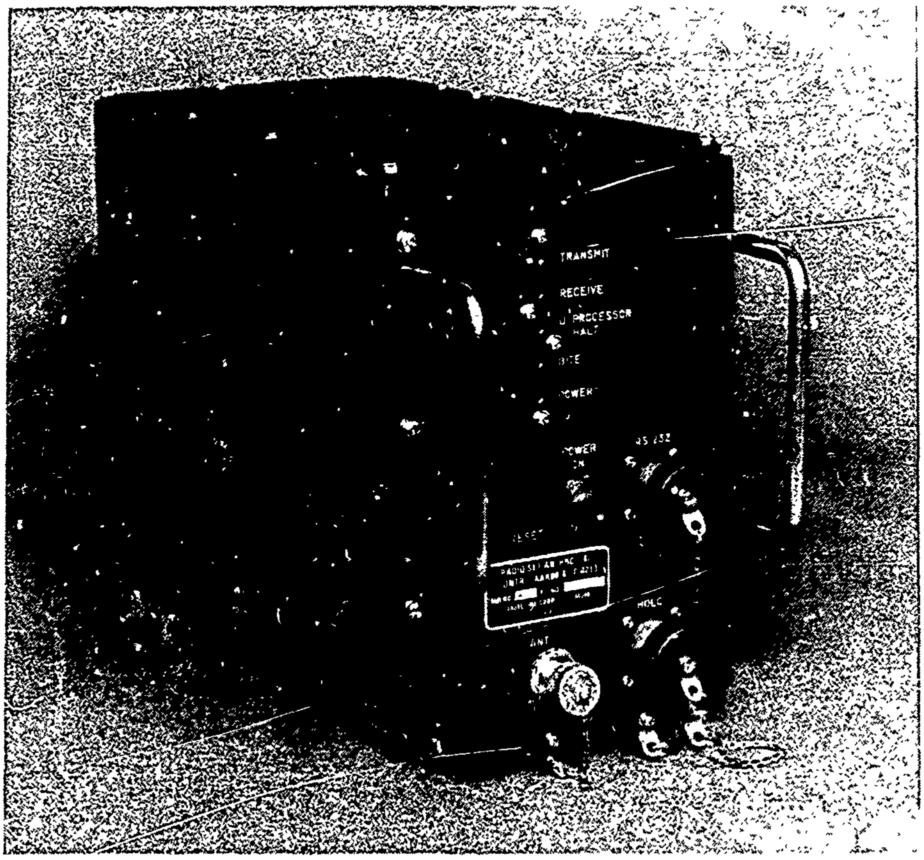

FIGURE 1 - LPR

destination. The packets can be routed either to another PR over the radio channel or in the case where the final destination is the attached device of this PR, the packets are sent directly over the HDLC interface. The SURAP1 protocols that run in the digital subsystem of the PRs encompass the physical, datalink, and network layers, as defined in ISO's Open Systems Interconnection Reference Model [5].

In order for a user to send data across a PRNET, a device (such as a host computer) must be attached to a PR via the HDLC wire interface. Since the DARPA PRNET is a part of the DARPA Experimental Internet System [6], the attached devices are responsible for running the DoD-standard internetwork-, transport-, and application-level protocols (IP, TCP, and TELNET). These protocols ensure that the end-to-end communication between hosts is reliable and robust and allow hosts on the PRNET to communicate with computers on various other packet-switched satellite, terrestrial, radio and local area networks that also participate in the DARPA Internet. A host computer may be directly interfaced to a PR. If a user wishes to send data across the PRNET from a terminal or other device that does not run the required protocols, a

network interface unit [7], Figure 2, may be used between the terminal or host and the PR. The NIU performs the necessary host-to-host and terminal-specific protocols. The PRNET can also be accessed from other networks via an internet gateway. In addition to supporting data, the PRNET protocols can also support a limited amount of digitized speech.

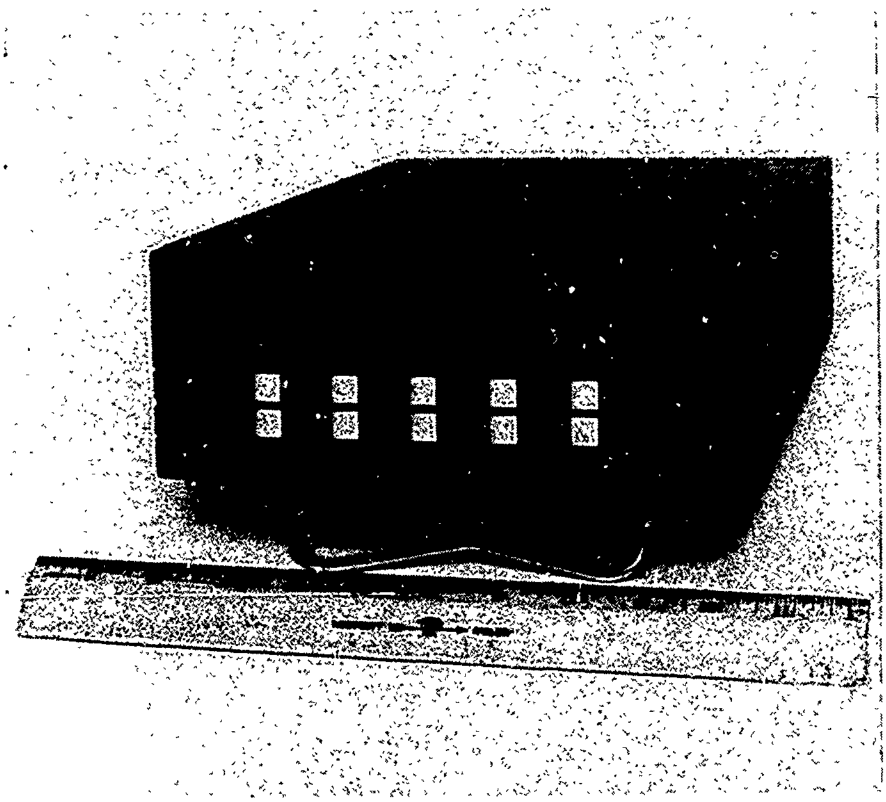

FIGURE 2 - NIU

A host computer function called the network monitor is used to aid in observing and analyzing the PRNET. Each PR continuously gathers measurements on bidirectional link quality, nodal capacity, and route characteristics. Attached devices collect statistics on end-to-end throughput and delays. The network monitor collects data from each of the PRs and attached devices and displays them graphically to aid the network operators and designers in characterizing and understanding the network behavior. The network monitor is an optional component of the network, and not required for network operation.

Figure 3 illustrates the PRNET with attached devices as a part of the Internet. Note that, organizationally, the devices lie outside the PRNET subnet: the network appears as a black box providing packet communication service between gateways and user devices.

3. SURAN PRNET Features

The PRNET provides, via a common radio channel, the exchange of data between computers that are geographically separated. As a communications

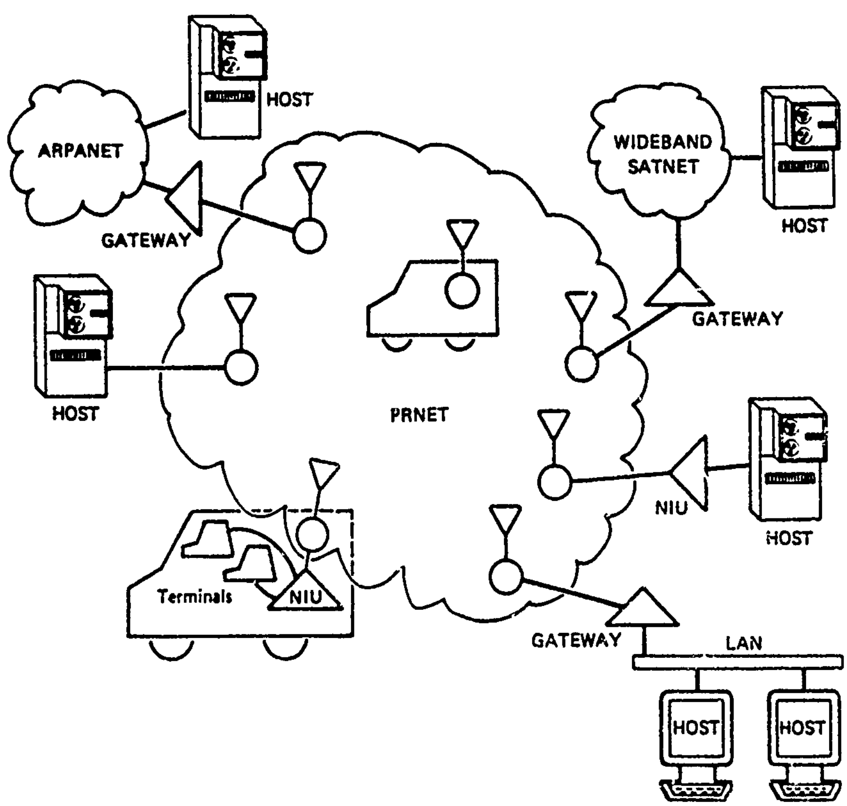

FIGURE 3 - PRNET IN INTERNET

medium, broadcast radio (as opposed to wires and antenna-directed radio) provides important advantages to the user of the network. One of the benefits is mobility; a PR can operate while in motion. Second, the network can be installed or deployed quickly; there are no wires to set up. A third advantage is the ease of reconfiguration and redeployment. SURAP1 takes advantage of broadcasting and common-channel properties to allow the PRNET to be expanded or contracted automatically and dynamically. A group of PRs leaving the original area simply departs. Having done so, it can function as an autonomous group and may later rejoin the original network or join another group.

SURAP1 is fully self-managing. A SURAP1 network is self-configuring upon network initialization, reconfigures upon gain or loss of PRs, and has dynamic routing. The network operator simply has to ensure that the PRs are deployed so that radio connectivity results in a "connected graph", ie; there is a path of radio links between every pair of nodes. Radios are then just turned on; the PR is intended to operate unattended. Once installed, the system discovers the radio connectivity between PRs and organizes routing strategies dynamically on the basis of this connectivity. After initialization, most communication networks maintain a static topology. A unique feature of the PRNET is the ease with which network topology can be altered without affecting the user's ability to communicate. Although RF connectivity is difficult to predict and may abruptly change in unexpected ways as mobile PRs move about, the self-managing procedures used in SURAP1 are capable of sensing the existing connectivity in real time and then exploiting this connectivity in order to continuously transport packets, all in a way that is totally transparent to the users.

The first version of the SURAN PRNET has fully distributed network management [8]. This feature greatly enhances the survivability of the network. Each PR gathers and maintains enough information about network topology so that it can make independent decisions about how to route data through the network to any destination. Thus there is no single point of vulnerability. The objective in gathering the information is to always maintain the "best" information about how to get to a destination PR. In SURAP1 the "best" route is defined as the shortest route with good connectivity on each hop.

SURAP1 provides a dynamic addressing capability known as logical addressing. With logical addressing, the relationship of an attached device to a PR may be altered as necessary. If a device is moved from one PR to another, or if it fails, its new status is made known to the network in the same manner. In addition, SURAP1 supports generic logical addressing. Generic

addressing allows a device to request service from any other device in a general category, e.g., any name server or any gateway. The packet is addressed to an ID that may belong to more than one device. The network will deliver the packet to the closest device with the requested generic ID.

4. SURAP1 Network Size

SURAP1 is designed to support a maximum of 138 entities, which can be any combination of PRs and attached devices, in a single network. For example, a typical network may be composed of 50 PRs, many of which have attached devices and some of which serve only as repeaters. Multiple PRNETs operating on different frequencies or spread sprectrum codes may be interconnected via internet gateways to support applications which require larger networks.

As the number of PRs increases, the number of neighbors (those PRs in direct radio horizon) per PR is likely to increase. SURAP1 allows each PR to store up to sixteen neighbors in its neighbor table. If however, PRs are sited more densely, creating neighborhoods of more than sixteen radios, the congested PRs employ an algorithm to determine their "logical" neighborhood, the effect of which is to limit to sixteen the number of "actual" neighbors that congested PRs track. If a neighbor PR is not stored in a PR's neighbor table, packets will still be forwarded to that neighbor but may be routed over multiple hops. The primary decision criterion of this algorithm is to exclude the prospective neighbor with the most neighbors in common. The algorithm is careful to prevent isolated cliques, that is, radios which are not able to communicate with the rest of the network. Therefore, the network dynamically accommodates network topologies that result in congested neighborhoods. However, performance is likely to suffer when "actual" neighborhoods are large due to congestion of the radio channels.

5. Forwarding Data Through the Network

It is the local broadcast nature of the PR that gives the PRNET its unique networking characteristic: a PR's transmission is received by all PRs within its radio horizon; e.g., in Figure 4, a connecting line indicates which PRs are within direct communications with each other. Because PRs L, N, and Q are all within radio horizon of M, a transmission by M can be received by all of these PRs; they are said to be one hop away from M. Note, however, that a transmission by, say, PR P can be received only by PR O. In general a PRNET consists of many PRs that are not all within radio horizon of each other, and packets must traverse multiple hops to reach their destination.

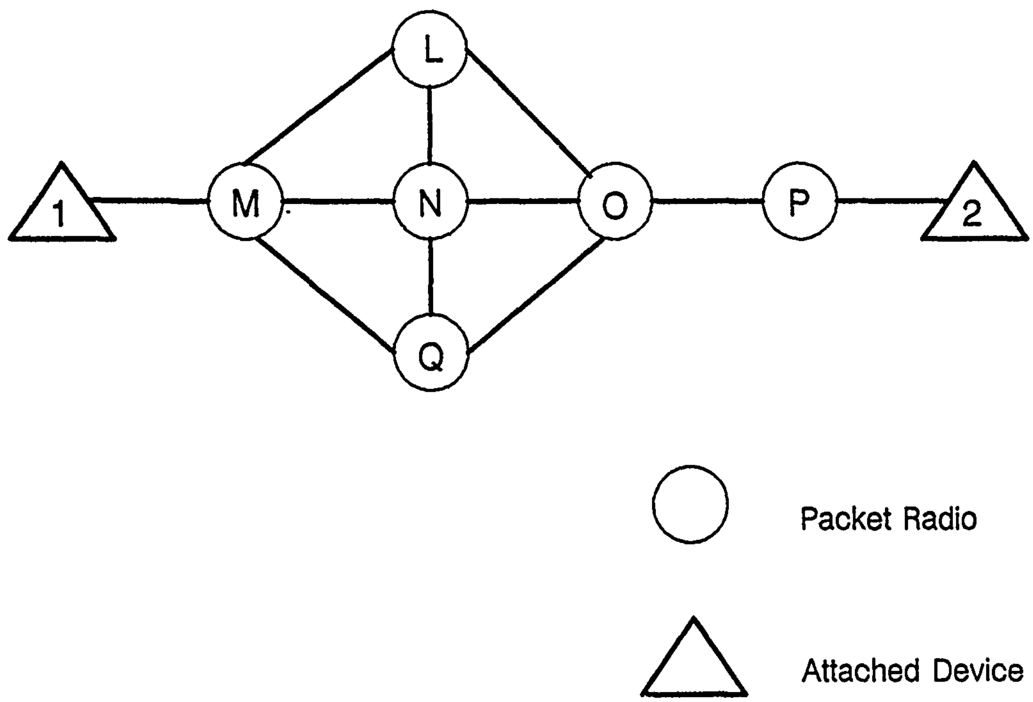

FIGURE 4 - PRNET

A packet typically traverses a single path through the network, and is acknowledged at every PR along the path. If a link fails, alternate routing is dynamically invoked to route around the bad link. Each PR along the route uses information in the packet header and information stored at the PR to determine the next PR enroute to the destination. For example, in Figure 4, Device 1 launches a packet destined for distant Device 2. The packet is sent across the wire interface to PR M. PR M uses information that it has stored in tables to learn that it should forward the packet on to PR N. Once N receives the packet from M, it similarly looks in its tables and learns that it should forward the packet on to PR O. In this manner, the packet is routed through the network towards Device 2. Once the packet has arrived at P, it is passed over the wire interface to Device 2.

If more than one packet is waiting to be transmitted at a node, a limited queue is formed. Transmissions are paced [9] to provide flow and congestion control, and as a result, no PR can transmit more than one-third of the time. SURAP1 dynamically chooses the transmit data rate on a packet by packet basis as a function of the estimated channel quality. The 400-kbps rate is used whenever possible to minimize channel usage. Because the 100-kbps rate provides an additional 6-dB receive processing gain over the 400-kbps

rate, it is used whenever the quality of the link appears to be deteriorating at the 400-kbps rate, but is still good at the lower rate.

While the pacing protocol greatly reduces the possibility of interference, irregularly spaced user traffic is bound to cause more than one PR to schedule transmissions which overlap in time, causing collisions. The carrier sense multiple access (CSMA) [12] protocol is employed to prevent a PR from transmitting at the same time a neighbor PR is transmitting.

The algorithms for forwarding and transmitting packets are designed to ensure fair service to all packets in the PRNET. However SURAP1 does offer one special type-of-service. The basic principle of this type-of-service is that preferential treatment is given to some packets at the expense of all the other packets in the network. The type-of-service in the PRNET was primarily designed for packetized speech experiments. It provides lower delay and, thus, higher throughput, but less reliability. A user can invoke type-of-service on a packet-by-packet basis.

6. Conclusion

In this paper we have described the first version of the DARPA SURAN PRNET. The primary component of the SURAN PRNET is the LPR. The protocols that run in this network are known as SURAP1. A SURAP1 network is self-managing, offers fully distributed routing and can support approximately 50 PRs. Research and development of future versions of more robust SURAP protocols which will provide survivable communications under adverse conditions is currently being conducted [10]. These new protocols will allow a single network to organize and manage thousands of PRs without internet gateways. In addition, they will employ enhanced link level transmission algorithms and more intelligent network routing algorithms to improve the network's performance and increase its adaptivity in the face of intelligent attacks on the network-level protocols and changing channel conditions.

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